

# **Summary Statistics for LC-HT01\_130808: Micro-CT Data Acquired at LLNL, Specimen 1 of 3**

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## Executive Summary

LC-HT01_130808				
Measured Density: 0.83 g/cm <sup>3</sup>		X-ray tube voltages (source filter materials)		
Parameter		$\mu_L$ 100 kV(Al), Al-BHC	$\mu_L$ 100 kV(Al), H <sub>2</sub> O-BHC	$\mu_H$ 160 kV (AlCu)
LAC	Mean Measured LAC (LMHU) <sup>1</sup>	1098	1108	757
	Standard Deviation/Mean	8%	7%	8%
	Entropy	5.95	5.74	5.58
<sup>L</sup> Z <sub>eff</sub>	From the mean measured LACs	7.76		
<sup>LW</sup> Z <sub>eff</sub>	From the mean measured LACs	7.26		
$\mu_L/\mu_H$	Using Al-BHC	1.45		
$\mu_L/\mu_H$	Using H <sub>2</sub> O-BHC	1.46		
QA	From Cu strip and References	See p.5		

**Table 1.** First-order statistics of the x-ray linear attenuation coefficient (LAC) in LC-HT01\_130808, the estimated value of the effective atomic number,  $Z_{\text{eff}}$  [1] and  $\mu_L/\mu_H$ .  $Z_{\text{eff}}$  is calculated from the ratio of  $\mu_L/\mu_H$ . Beam hardening compensation has been applied to  $\mu_L$  using both aluminum (<sup>L</sup>Z<sub>eff</sub>) and water (<sup>LW</sup>Z<sub>eff</sub>) beam hardening parameters.

Using x-ray micro computed tomography (MicroCT), we have characterized the linear attenuation coefficients (LAC),  $\mu$ , of a sample of a dry powder material, lithium carbonate (LC). The specimen was prepared at Lawrence Livermore National Laboratory (LLNL), loaded into a 60mL low density polyethylene (LDPE) bottle. After completed packing, the specimen was scanned following the protocol for MicroCT measurements under Test Plan 79 [2].

This particular specimen, LC-HT01\_130808, recorded the bulk packing density (mass of sample divided by volume of sample) shown above. Two additional preparations were made and analyzed [3-4]. We used the computer program IMGREC to reconstruct the CT images. The values of the key parameters used in the x-ray data capture and image reconstruction are given in this report. Additional experimental details may be found in the SOP [5] and a separate document [6]. To characterize the statistical distribution of LAC values in each CT image, we first isolated an ~80% region or segment of volume elements (“voxels”) lying completely within the sample, away from the walls of the container. We then calculated the mean value, standard deviation and entropy for (a) the high and low energy image segments and for (b) their digital gradient images<sup>2</sup>. The statistics of the initial image of LAC values are called “first order statistics;” those of the gradient image, “second order statistics.” See Seetho [7] for details of the analysis used to obtain the numbers reported in this document.

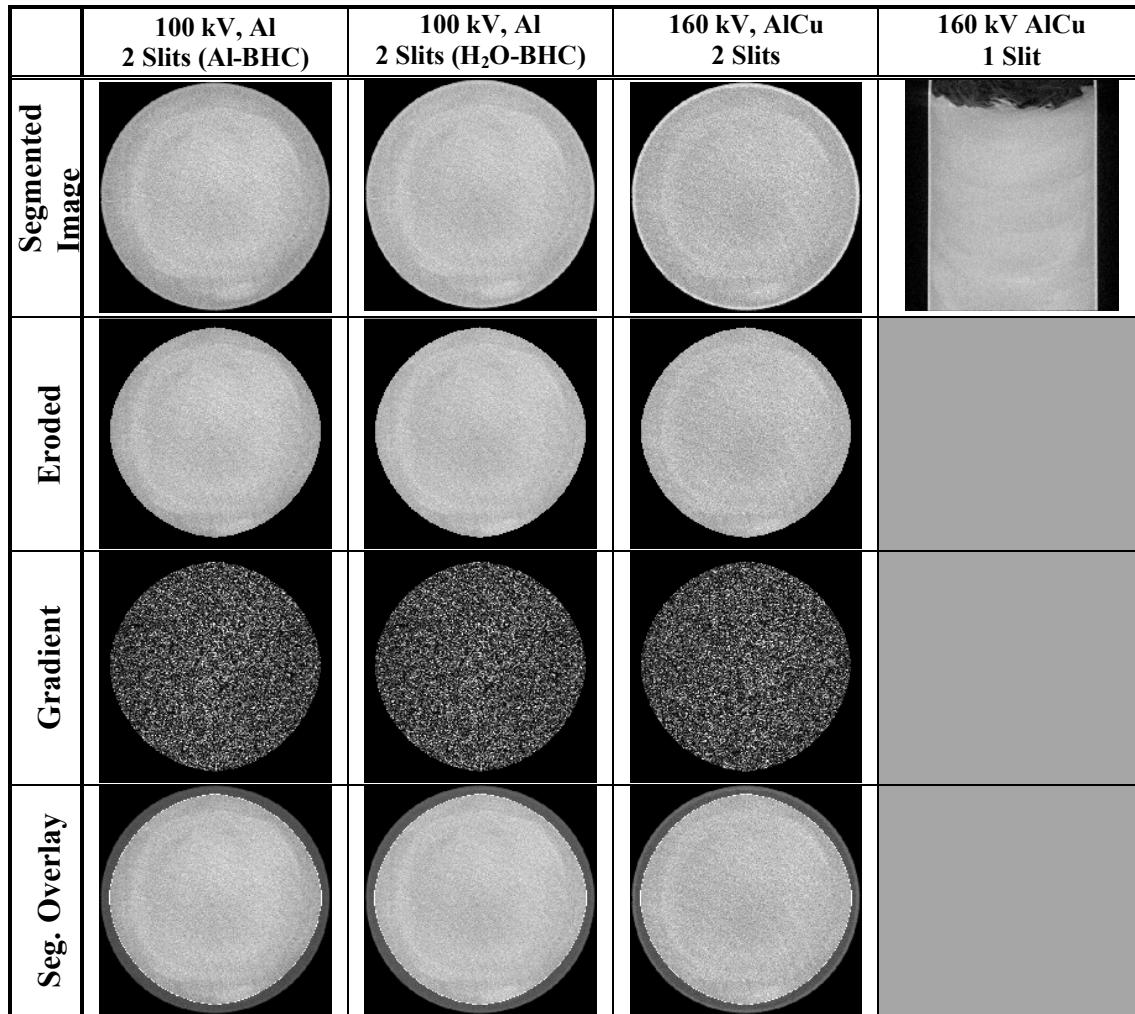
<sup>1</sup> LMHU: “LLNL modified Hounsfield units with respect to water.” To obtain the LAC in LMHU for some material at any energy, we multiply by 1000 and divide by the LAC of water at an x-ray energy of 160 kV with aluminum and copper filters.

<sup>2</sup> A digital gradient image of a given image was obtained by taking the absolute value of the difference between the initial image and that same image offset by one voxel horizontally, parallel to the rows of the x-ray detector array.

**Summary of LC\_HT01\_130808 X-ray Statistics****Report Date:** December 13, 2013**Report Prepared by:** Isaac Seetho  
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*Organization***QA:** Isaac Seetho  
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*Organization***Material ID(s):** LC\_HT01\_130808

Source			Collimator	Beam Hardening	Sample Preparation	X-ray Measurement	Linear Attenuation Coefficient (LAC)							
Bias (kV)	Filters		Number of slits	Parameter Source	Date	Date	Statistic	1 <sup>st</sup> order	2 <sup>nd</sup> order					
	Material	Thickness												
100	Al	1.943 mm	2	H <sub>2</sub> O	8/6/2013	8/8/2013	Mean	1108	57					
							Std. Dev.	75	44					
							Entropy	5.74	5.03					
100	Al	1.943 mm	2	Al	8/6/2013	8/8/2013	Mean	1098	63					
							Std. Dev.	93	48					
							Entropy	5.95	5.12					
160	Al Cu	1.943 mm 1.905 mm	2	None	8/6/2013	8/8/2013	Mean	757	54					
							Std. Dev.	64	41					
							Entropy	5.58	4.97					
<sup>L</sup> Z <sub>eff</sub>	Based on measured LAC (Al-BHC)							7.76						
<sup>LW</sup> Z <sub>eff</sub>	Based on measured LAC (H <sub>2</sub> O-BHC)							7.26						
$\mu_L/\mu_H$	Based on measured LAC (Al-BHC)							1.45						
$\mu_L/\mu_H$	Based on measured LAC (H <sub>2</sub> O-BHC)							1.46						

**Table 2.** Key statistics [8] for x-ray measurements of Linear Attenuation Coefficient (LAC).  ${}^L Z_{eff}$  is determined from 100 kV (Al) to 160 kV (AlCu) LAC ( $\mu_L/\mu_H$ ) as given in reference [1]. The statistics here are from the 2-slit image data (not the 1-slit open image data).**Comments:** \_\_\_\_\_



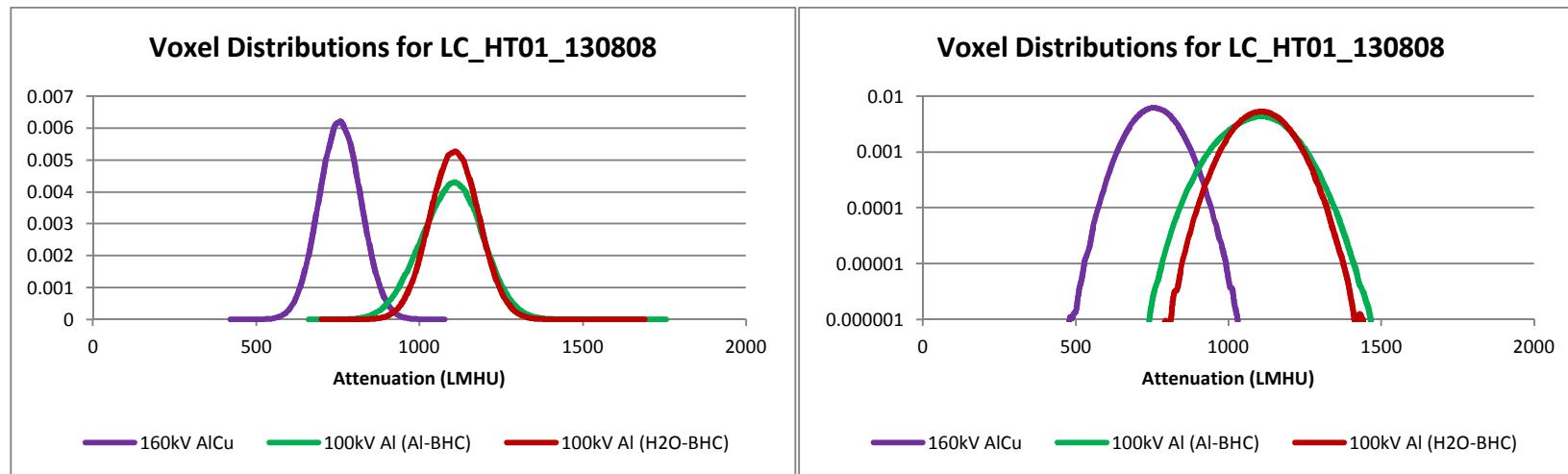
**Figure 1.** X-ray slice images with  $150\mu\text{m} \times 150\mu\text{m} \times 150\mu\text{m}$  voxels. Raw data (top row), segmented images (second row), eroded images (third row) used to calculate first order statistics. Fourth row, difference or gradient image used for second-order statistics. Images not to scale and use different gray scales to obtain maximum contrast. Single slit images (top right) are used for a qualitative visual assessment of homogeneity.

#### Comments/Observations on Appearance of Sample (texture, color, other):

The specimen displays a fine powder texture. There is a visible ring in the center of the horizontal slice image suggesting compression oriented in the center of the cylinder, and visible striations in the vertical slice image suggesting progressive compression of the material.

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## SUPPLEMENTAL ANALYSIS



**Figure 2.** KDE histograms of values of the linear attenuation coefficient (LAC) for LC-HT01\_130808 for two x-ray source settings (linear plots – left; semi-log plots – right).

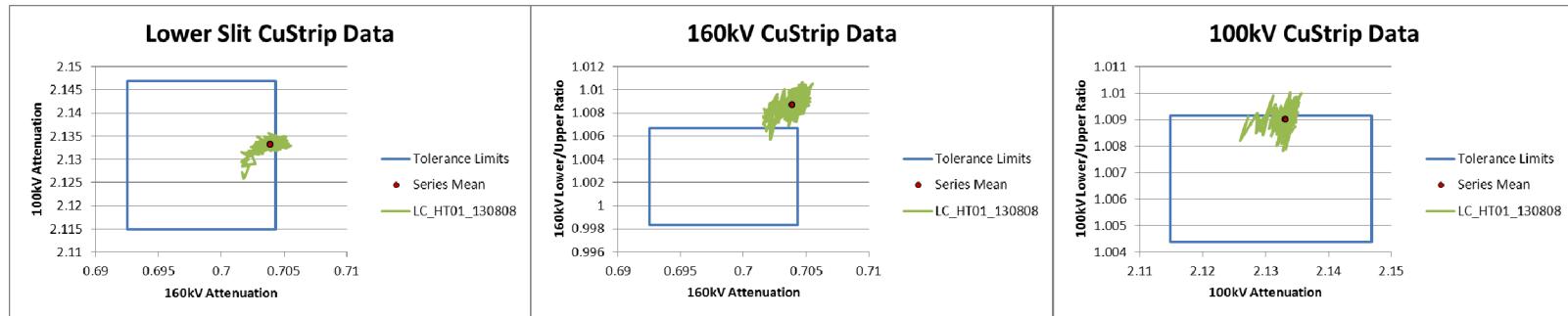
**Comments/Observations on Histograms:** These histograms are made with a Gaussian Kernel Density Estimator (KDE) [8, 9] using 150- $\mu\text{m}$  voxel upper-slit CT images.

## Reference Specimens

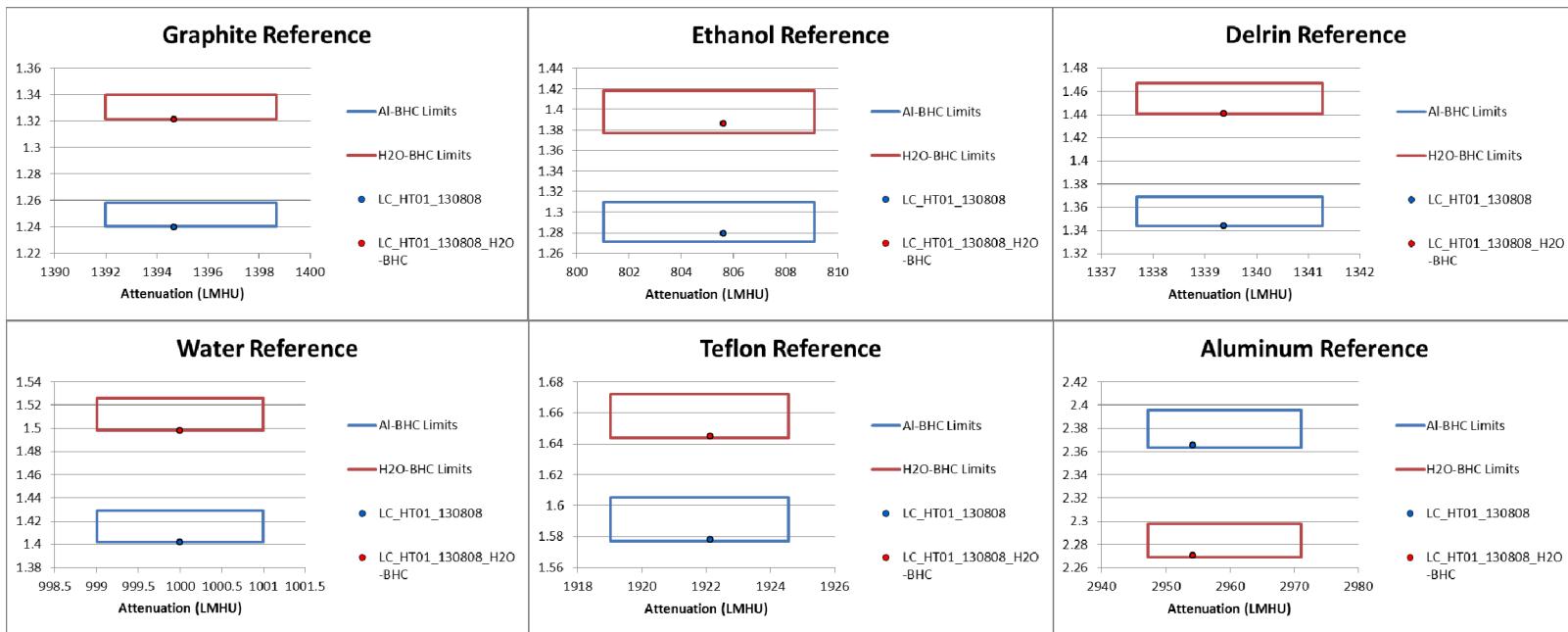
	Parameter	graphite	ethanol	Delrin*	water	Teflon**	aluminum***
<b>100kV, Al (Al-BHC)</b>	Mean (LMHU)	1729	1031	1800	1402	3033	6988
	Std Dev LMHU	82	59	82	55	89	141
<b>100kV, Al (H2O-BHC)</b>	Mean (LMHU)	1842	1116	1930	1498	3161	6707
	Std Dev LMHU	77	60	76	54	65	229
<b>160kV, AlCu</b>	Mean (LMHU)	1395	806	1339	1000	1922	2954
	Std Dev LMHU	61	47	57	47	59	74

**Table 3.** Linear attenuation coefficients of six reference materials as measured simultaneously with LC-HT01\_130808.

\* Acetron® GP copolymer. \*\*Enflo Corp. PTFE. \*\*\*T6061 alloy.



**Figure 3.** Copper strip ratio value for 160kV is above limits. These tolerance limits were defined using a set of scans spanning from April through May 2013.



**Figure 4.** Reference materials are within the defined tolerance limits, except for the graphite and water ratios (which are just below bounds). These tolerance limits were defined using a set of scans spanning from April through May 2013.

## Micro-CT System Configuration

1. Scan Location Site: LLNL HEAF
2. Source: Yxlon D09 450 kV Tube; Mfr. Catalog Number: 9421-172-33503; S/N 21-5204
3. Detector: Thales Flashscan 33 with Lanex Fine Gadolinium Oxysulfate Scintillator Screen; s/n 91106194
4. Rotation control system. Controller: Newport Model ESP7000 SN: 1250
5. Carousel: LLNL 2-tray, 6" Dia.
6. Data capture computer: Dell DHM/J4271

## Micro-CT Scan Parameters

1. Scan Geometry:<sup>1</sup> SOD (mm): 1131.0 ODD (mm): 298.7  
Number of positions: 400 Angular Range: 200° Angular Increment: 0.5°
2. Number of Frames averaged per Image: 4
3. Integration time per frame: See p 7.

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<sup>1</sup> Distances are those recorded in the .sct file for this experiment and are the values used in image reconstruction.

## File Storage Locations for X-ray Data Specimen

### Root Data Path:

\Working\TP79\_IMXXXXXX\_Microstructure\_Studies\_V1\LLNL\None\HEAFCAT\None\LC\_HT01\_130808\Test\_Data\{sub directory}\

Specimen ID	Date	Radiographer	Slits	kV	mA	Al Filter (mm)	Cu Filter (mm)	Integration dpix Setting [time/frame (s)]	{sub directory}	File Name
LC_HT01_130808	130808	Morales	2	100	1.1	1.943	0	8 [2.8s]	LC_HT01_130808_100Al	LC_HT01_100Al_nn.sdt <sup>1</sup>
	130808	Morales	2	160	4.35	1.943	1.905	8 [2.8s]	LC_HT01_130808_160AlCu	LC_HT01_160AlCu_nn.sdt
	130808	Morales	1	160	4.35	1.943	1.905	8 [2.8s]	LC_HT01_130808_160AlCu1slit	LC_HT01_160AlCu1slit_nn.sdt

### Dark current, mid-range, bright field and $I_o$

### Root Data Path:

\Working\TP79\_IMXXXXXX\_Microstructure\_Studies\_V1\LLNL\None\HEAFCAT\None\LC\_HT01\_130808\Test\_Data\{sub directory}\

Slits	kV	Filter	{sub directory}	Dark Image File Name	Mid-Brightness Image File Name	Max Brightness Image File Name	$I_o$ Image File Name
2	100	Al	LC_HT01_130808_100Al	LC_HT01_100AldrkR.sdt	LC_HT01_100AlmidR.sdt	LC_HT01_100AllitR.sdt	LC_HT01_100Albak.sdt
2	160	AlCu	LC_HT01_130808_160AlCu	LC_HT01_160AlCudrkR.sdt	LC_HT01_160AlCumidR.sdt	LC_HT01_160AlCulitR.sdt	LC_HT01_160AlCubak.sdt
1	160	AlCu	LC_HT01_130808_160AlCu1slit	LC_HT01_160AlCu1slitdrkR.sdt	LC_HT01_160AlCu1slitmldR.sdt	LC_HT01_160AlCu1slitlitR.sdt	LC_HT01_160AlCu1slitbak.sdt

<sup>1</sup> nn - is the CT angular index number (0 through 399) for each individual data file

## Reconstruction

**Reconstructed by:** Kenneth E. Morales

**Date:** 8/8/2013

**Location:** LLNL

**Computer:** Dell Precision 690

### Reconstruction Software

**Software:** IMGREC

**Version:** 2.8.1.1c11

**Beam hardening compensation:** Only for 100 kV Al filtered data using Al and H<sub>2</sub>O reference materials for compensation.

### Script Files

LLNL\_script\_LC\_HT01\_100Al.txt

LLNL\_script\_LC\_HT01\_160AlCu.txt

LLNL\_script\_LC\_HT01\_160AlCu1slit\_tw\_WDB.txt

LLNL\_script\_H2OBHC\_LC\_HT01\_100Al.txt

## Reconstructed Specimen Files

### Root Data Path:

\Working\TP79\_IMXXXXXX\_Microstructure\_Studies\_V1\LLNL\None\HEAFCAT\None\LC\_HT01\_130808\Reconstruction\Recon\_130808\{sub directory}\

Slits	kV	Filter	{sub directory}	Reconstruction file name
2	100	Al	LC_HT01_130808_100Al	recobj_nn <sup>1</sup> .sdt
2	100	Al	H2O_Recon\LC_HT01_130808_100Al	recobj_nn.sdt
2	160	AlCu	LC_HT01_130808_160AlCu	recobj_nn.sdt
1	160	AlCu	LC_HT01_130808_160AlCu1slit	recry_nn.sdt , ry_nn.sdt

### Observations:

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<sup>1</sup> nn - is the index number for each reconstruction file, modified by an offset corresponding to the frame subsection extracted and analyzed.

## Analysis

**Analysis by:** Isaac Seetho

**Date:** 8/8/2013

**Location:** LLNL

**Computer:** Dell Precision T7500

### Analysis Software

**Software:** MATLAB

**Version:** R2010b

### GUI Function/Script Files

micro\_ct\_gui\_1\_3.m<sup>1</sup>

custrip\_gui\_split.m

## Reference & Specimen Analysis Files

\Working\TP79\_IMXXXXXX\_Microstructure\_Studies\_V1\LLNL\None\HEAFCAT\None\LC\_HT01\_130808\Analyses\LC\_HT01\_130808\_analysis\_IMS\_130808\

Analysis File	LC_HT01_130808_characterization.xlsx
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\Working\TP79\_IMXXXXXX\_Microstructure\_Studies\_V1\LLNL\None\HEAFCAT\None\LC\_HT01\_130808\Analyses\LC\_HT01\_130808\_H2O-HBC\_analysis\_IMS\_130808\

Analysis File	LC_HT01_130808_H2O-HBC_characterization_Corrected.xlsx
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## Copper Strip Analysis Files

### Root Data Path:

\Working\TP79\_IMXXXXXX\_Microstructure\_Studies\_V1\LLNL\None\HEAFCAT\None\LC\_HT01\_130808\Analyses\LC\_HT01\_130808\_custrip\_IMS\_130808\

Aggregate Statistics	Stats_LC_HT01_130808_W80xH7.xls
Mean Value Time Series	Custrip_LC_HT01_130808_W80xH7.xls

<sup>1</sup> Analysis using the MicroCT GUI is done according to the steps outlined in reference [7].

## REFERENCES

1. Jeffrey S. Kallman, Daniel J. Schneberk, Harry E. Martz, Jr., *Two-energy Ratio Method to Determine Zeff from Reference Materials: A Comparison of an Explosive and a Simulant*, Version 3, Lawrence Livermore National Laboratory, LLNL-TR-491153, June 24, 2011.
2. Stephen Azevedo, Jeffrey S. Kallman, Harry E. Martz, Jr., *TP79 – Microstructure Studies Using MicroCT and EDS for DHS R&D*, Lawrence Livermore National Laboratory.
3. Isaac M. Seetho, Kenn E. Morales, W. Travis White, III, Harry E. Martz, Jr., *Summary Statistics for LC-HT02\_130812: Micro-CT Data Acquired at LLNL, Specimen 2 of 3*, Lawrence Livermore National Laboratory, LLNL-TR-655001, December 13, 2013.
4. Isaac M. Seetho, Kenn E. Morales, W. Travis White, III, Harry E. Martz, Jr., *Summary Statistics for LC-HT03\_130813: Micro-CT Data Acquired at LLNL, Specimen 3 of 3*, Lawrence Livermore National Laboratory, LLNL-TR-654999, December 13, 2013.
5. “Standard Operating Procedure — Industrial Computed Tomography System Data Collection of Home-Made Explosives,” U.S. Department of Homeland Security Science and Technology Directorate, DHS/STD/TSL-xx-xx, July 9, 2009.
6. Jerel A. Smith, Daniel J. Schneberk, Jeffrey S. Kallman, Harry E. Martz, Jr., David Hoey, *Documentation of the LLNL and Tyndall Micro-Computed-Tomography Systems*, Version 091216, Lawrence Livermore National Laboratory, LLNL-TR-421377, December 17, 2009.
7. Isaac Seetho, *MicroCT: Analysis of CT Reconstructed Data of Home Made Explosive Materials Using the Matlab MicroCT Analysis GUI*, Lawrence Livermore National Laboratory, IDD-MCT-SOP-007, January 13, 2011.
8. Harry E. Martz, Jr., and Carl Crawford, *Validation of Explosive Simulants Requirement Specification*, Version 12, Lawrence Livermore National Laboratory, LLNL-TR-416983-REV 1, October 26, 2009.
9. B. W. Silverman, *Density Estimation*, Chapman and Hall, 1986.